

HIGH-SPEED DIGITAL DESIGN

A Handbook of Black Magic

HOWARD W. JOHNSON, PH.D.
Signal Consulting, Inc.

MARTIN GRAHAM, PH.D.
University of California at Berkeley

For book and bookstore information



<http://www.phptr.com>



Prentice Hall PTR, Upper Saddle River, New Jersey 07458

Contents

Preface *ix*

1 Fundamentals 1

- 1.1 Frequency and Time 1
- 1.2 Time and Distance 6
- 1.3 Lumped Versus Distributed Systems 7
- 1.4 A Note About 3 dB and RMS Frequencies 8
- 1.5 Four Kinds of Reactance 10
- 1.6 Ordinary Capacitance 11
- 1.7 Ordinary Inductance 17
- 1.8 A Better Method for Estimating Decay Time 22
- 1.9 Mutual Capacitance 25
- 1.10 Mutual Inductance 29

2 High-Speed Properties of Logic Gates 37

- 2.1 Historical Development of a Very Old Digital Technology 37
- 2.2 Power 39
- 2.3 Speed 59
- 2.4 Packaging 66

| | | |
|----------|---|------------|
| 3 | Measurement Techniques | 83 |
| 3.1 | Rise Time and Bandwidth of Oscilloscope Probes | 83 |
| 3.2 | Self-inductance of a Probe Ground Loop | 86 |
| 3.3 | Spurious Signal Pickup from Probe Ground Loops | 92 |
| 3.4 | How Probes Load Down a Circuit | 95 |
| 3.5 | Special Probing Fixtures | 98 |
| 3.6 | Avoiding Pickup from Probe Shield Currents | 104 |
| 3.7 | Viewing a Serial Data Transmission System | 108 |
| 3.8 | Slowing Down the System Clock | 110 |
| 3.9 | Observing Crosstalk | 111 |
| 3.10 | Measuring Operating Margins | 113 |
| 3.11 | Observing Metastable States | 120 |
| 4 | Transmission Lines | 133 |
| 4.1 | Shortcomings of Ordinary Point-to-Point Wiring | 133 |
| 4.2 | Infinite Uniform Transmission Line | 140 |
| 4.3 | Effects of Source and Load Impedance | 160 |
| 4.4 | Special Transmission Line Cases | 167 |
| 4.5 | Line Impedance and Propagation Delay | 178 |
| 5 | Ground Planes and Layer Stacking | 189 |
| 5.1 | High-Speed Current Follows the Path of Least Inductance | 189 |
| 5.2 | Crosstalk in Solid Ground Planes | 191 |
| 5.3 | Crosstalk in Slotted Ground Planes | 194 |
| 5.4 | Crosstalk in Cross-Hatched Ground Planes | 197 |
| 5.5 | Crosstalk with Power and Ground Fingers | 199 |
| 5.6 | Guard Traces | 201 |
| 5.7 | Near-End and Far-End Crosstalk | 204 |
| 5.8 | How to Stack Printed Circuit Board Layers | 212 |
| 6 | Terminations | 223 |
| 6.1 | End Terminators | 223 |
| 6.2 | Source Terminators | 231 |
| 6.3 | Middle Terminators | 235 |
| 6.4 | AC Biasing for End Terminators | 236 |
| 6.5 | Resistor Selection | 239 |
| 6.6 | Crosstalk in Terminators | 244 |
| 7 | Vias | 249 |
| 7.1 | Mechanical Properties of Vias | 249 |
| 7.2 | Capacitance of Vias | 257 |
| 7.3 | Inductance of Vias | 258 |
| 7.4 | Return Current and Its Relation to Vias | 260 |

| | | |
|-----------|---|------------|
| 8 | Power Systems | 263 |
| 8.1 | Providing a Stable Voltage Reference | 263 |
| 8.2 | Distributing Uniform Voltage | 268 |
| 8.3 | Everyday Distribution Problems | 279 |
| 8.4 | Choosing a Bypass Capacitor | 281 |
| 9 | Connectors | 295 |
| 9.1 | Mutual Inductance—How Connectors Create Crosstalk | 295 |
| 9.2 | Series Inductance—How Connectors Create EMI | 300 |
| 9.3 | Parasitic Capacitance—Using Connectors on a Multidrop Bus | 305 |
| 9.4 | Measuring Coupling in a Connector | 309 |
| 9.5 | Continuity of Ground Underneath a Connector | 312 |
| 9.6 | Fixing EMI Problems with External Connections | 314 |
| 9.7 | Special Connectors for High-Speed Applications | 316 |
| 9.8 | Differential Signaling Through a Connector | 319 |
| 9.9 | Power Handling Features of Connectors | 321 |
| 10 | Ribbon Cables | 323 |
| 10.1 | Ribbon Cable Signal Propagation | 324 |
| 10.2 | Ribbon Cable Crosstalk | 329 |
| 10.3 | Ribbon Cable Connectors | 336 |
| 10.4 | Ribbon Cable EMI | 338 |
| 11 | Clock Distribution | 341 |
| 11.1 | Timing Margin | 341 |
| 11.2 | Clock Skew | 343 |
| 11.3 | Using Low-Impedance Drivers | 346 |
| 11.4 | Using Low-Impedance Clock Distribution Lines | 348 |
| 11.5 | Source Termination of Multiple Clock Lines | 350 |
| 11.6 | Controlling Crosstalk on Clock Lines | 352 |
| 11.7 | Delay Adjustments | 353 |
| 11.8 | Differential Distribution | 360 |
| 11.9 | Clock Signal Duty Cycle | 361 |
| 11.10 | Canceling Parasitic Capacitance of a Clock Repeater | 362 |
| 11.11 | Decoupling Clock Receivers from the Clock Bus | 364 |
| 12 | Clock Oscillators | 367 |
| 12.1 | Using Canned Clock Oscillators | 367 |
| 12.2 | Clock Jitter | 376 |

| | | |
|----------|---------------------------------|------------|
| | Collected References | 385 |
| A | Points to Remember | 389 |
| B | Calculation of Rise Time | 399 |
| C | MathCad Formulas | 409 |
| | Index | 441 |